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# Mutual Action of Lubricating Oils And Bearing Metals

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Mutual Action of Lubricating
Oils and Bearing Metals

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# THE MUTUAL ACTION OF LUBRICATING OILS
# and
# BEARING METALS.

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A THESIS

presented by

Charles C. Hotchkiss

and

Joseph N. Schumacher

to the

President and Faculty

of the

Armour Institute of Technology

for the degree of

Bachelor of Science in Chemical Engineering

having completed

the

prescribed course of study.

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THE MUTUAL ACTION OF LUBRICATING OILS AND BEARING METALS.

In the first place it may be stated that very little work has been done or published on the above subject. However the following summary gives the results of investigation in this direction.

Mr. C. W. Volney experimenting on brass found that of the different oils used olive oil had the most action and lard oil the least action. (Analyst Vol 8 p. 68).

Mr. W. H. Watson found that seal oil had more action than sperm on copper. (Chemical News Vol. 36 p. 200).

Dr. Stevenson Mac Adam, investigating the action of paraffin burning oils on metals concluded that the action varied with the different samples and was not traceable to the presence of impurities. (Jour. Chem. Soc. Vol. 8 p. 355).

On the other hand Engler maintains that mineral oils have no action whatever on metals if free from air. (Chem. News Vol.41).

Iltyd I. Redwood has made the most extensive investigations of any experimenter in this line of research. His experiments were made primarily for the purpose of determining what fixed oils were best suited for mixing with mineral oils for lubricating purposes. He used metals in common use and treated them with oils in corked tubes at an average temperature of 80 degrees Fahrenheit in the summer and 50 degrees Fahr. in the winter. His work in the main would seem to show that with mineral oil there is some action, in spite of the fact that the oil was out of contact with the air. This conclusion is apparently in contradiction to Englers' view who contended that mineral oils have no action on metals if free from air.

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Redwood's results are as follows:-

Iron is least affected by seal oil, and most by tallow oil.

Brass is not affected by rape oil, least by seal oil, and most by olive oil.

Tin is not affected by rape oil, least by olive oil, and most by cotton-seed oil.

Lead is least affected by olive oil, and most by whale oil; but whale, lard, and sperm oils all act to very nearly the same extent on lead.

Zinc seems, by the four actual weighings that were of any value, to be not acted on by mineral lubficating oil, least by lard oil, and most by sperm oil.

Copper is not affected by mineral lubricating oil, least by sperm oil, and most by tallow oil.

Also with regard to the action of the different oils Redwood found that

Mineral Lubricating Oil has no action on zinc and copper, acts least on brass, and most on lead.

Olive oil acts least on tin and most on copper.

Rape oil has no action on brass and tin, acts least on iron, and most on copper.

Tallow oil acts least on tin and most on copper.

Lard oil acts least on zinc and most on copper.

Cotton-seed oil acts least on lead and most on tin.

Sperm oil acts least on brass and most on zinc.

Whale oil has no action om tin, acts least on brass, and most on lead.

Seal oil acts least on brass and most on copper.

The object of the present investigation is to determine the action of mineral lubricating oils, both purely mineral and compounded with varying amounts of organic oils, on standard bearing metals, under conditions approximating as closely as possible those met with in practice. It is also part of the investigation to compare the action of the oils on the metals both exposed to and out of contact with the air, other conditions being the same.

As to the probable influence of impurities in the oils on their action on the metals it might be well first to briefly consider the method of manufacture of the oils noting where any impurities might enter into them.

The crude petroleum as it comes from the well is usually a thin, oily liquid, ranging from pale yellow to dark green and sometimes black in color, having a very offensive odor, very volatile and inflammable. The crude oil after being pumped through pipe lines is run into stills where it is subjected to heat, first by steam when the lighter vapors pass off and are condensed. This first product of the still is the"naphtha distillate." This is redistilled to form the various grades of gasolines and benzines. After the burning oils are collected the oil in the still is subjected to a more intense heat, and as the process of distillation goes on the heavier oils remaining in the still are known as "residual oils", which are drawn off and used to make the various grades of heavy engine and machinery oils. The paraffin wax is removed by a refrigerating process. After the various grades of engine and machinery oils are drawn from the stills, the remaining oil is subjected to a still high-

er temperature and when taken out is known as"cylinder stock", which is filtered and compounded wiyh various animal or vegeta= ble oils in order to make it into the various grades of cylin- der oil. These oils will vary in their color and quality accord- ing to the crude oil from which they were made and the process used in making them.

Now due to the intense heat applied the molecular tension of the oil tends to become diminished. This is a detrimental factor since a good lubricant must have sufficient "body" to keep the bearing surfaces between which it is interposed from coming into contact. The fractions are usually washed with nitric acid to remove the tar and"bloom" thereby giving rise to the possibility of there being free acid in the final lubricating product. Naturally free acid in a lubricating oil has a corro- sive influence on the metals with which it is brought in con- tact.

The following method of procedure was adopted:-
The bearing metals were first planed so as to obtain samples for analysis. The method of sampling was that ordinarily known as"quartering". Next the metals were brought down to conven- ient size by means of the milling machine. These samples of metals were thoroughly cleaned with alcohol and ether, dried in an oven and weighed. The metals were then placed in test- tubes together with 20 cubic centimeters of each sample of oil. Half of these tubes were corked and the other half exposed to the air.

Those test-tubes open to the air were provided with small glass tubes reaching to the bottom for the purpose of passing in air. The air was forced in by means of an hydraulic arrangement, in principle depending upon the fact that the amount of air displaced is equal to the volume of water added. By this means a measured amount of air could be sent through the oil. The samples were so aerated that about one and one-third liters of air, (0.047 cu. ft.), per week were sent through each sample. The temperature maintained was 100 degrees F., a good average for the temperature of bearings in practice. The color of the oils at the beginning and also at the end of the tests were noted by comparing with the standard color sheets in Mullikens' "Identification of Pure Organic Compounds". The character of the surface of the metals was also examined after exposure to the oils. After exposure the metals were thoroughly cleaned, washed with ether, and alcohol, and then carefully dried, first with cotton wool and then in an oven and finally weighed.

Methods for the analysis of the metals.

1. White or Babbitt metals and Phosphor Bronze.

A sample of the alloy is cut into very fine fragments, this materially aiding solution and also enabling an accurate sample to be taken. Then proceed as follows.

Tin and Antimony.--Treat one gram of the sample with 15 cc.

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Note:- The test extended over a period of 81 days, from February 27th to May 18th. In the meantime complete analyses of the bearing metals were made together with such tests and analyses of the lubricating oils as were considered essential to the investigation.

of nitric acid(Sp.G. 1.4); place on the hot plate and evaporate off the excess of acid. The tin and antimony are precipitated as oxides and are filtered off onto an asbestos mat in a Gooch crucible; wash with a dilute solution of ammonium nitrate. The filtrate is used for the determination of the other metals. The combined oxides of antimony and tin are dissolved in the smalles possible quantity of hot dilute hydrochloric acid; hydrogen sulphide is passed through the warm solution till the antimony and tin are completely precipitated as sulphides; the sulphides are filtered off and dissolved in ammonium sulphide solution; traces of copper and lead which might be present are dissolved off the filter paper with hot dilute nitric acid and added to the first filtrate.

The ammonium sulphide solution of antimony and tin is poured with vigorous stirring into a hot solution of 25 grams of oxalic acid in 200 cc. of water. The solution is heated to boiling and hydrogen sulphide is passed for about 15 minutes. The precipitate is filtered off immediately and washed with hot water containing hydrogen sulphide. It is dissolved in ammonium sulphide and the treatment with oxalic acid and hydrogen sulphide repeated. The precipitate of antimony sulphide is filtered off and washed with water containing a little hydrogen sulphide. The moist precipitate into a large porcelain dish with water. The small portion still still adhering to the paper is dissolved in a little warm ammonium sulphide and the solution allowed to flow into the crucible. The solution is evaporated on the water bath after the addition of a few cc. of concentrated nitric

acid. If sulphur separates, a little liquid bromine is added when the solution has become quite concentrated. When the globule of sulphur has disappeared, expel the excess of nitric acid by heating on the hot plate, finally heating to full redness on the Bunsen's burner. Cool a little, sprinkle a little ammonium carbonate over the precipitate, and ignite again to completely expel sulphuric acid, and weigh as antimony tetroxide($Sb_2O_4$).

The oxalic acid solution of the tin with the addition of 5 cc. of concentrated sulphuric acid is evaporated to a small bulk. The solution is cooled, cautiously diluted with water, and hydrogen sulphide passed to insure complete precipitation of the tin. Wash the precipitate with water containing ammonium acetate and a little acetic acid, dry, ignite, and weigh as stannic oxide ( SnO2).

Lead.-- Add 20 cc. of concentrated sulphuric acid to the filtrate from the tin and antimony oxides, transfer to a large porcelain evaporating dish, place on the hot plate and evaporate to $SO_3$ fumes. The solution is then cooled, diluted to 50 cc. with distilled water and ten cc. of alcohol added. The lead sulphate is filtered off on the asbestos mat of a Gooch crucible ~~X~~ washed a few times with 1% sulphuric acid and finally with alcohol, dried in the oven at 95 deg. C. and weighed.

Copper.--The filtrate from the lead is heated to boiling to expel the alcohol and the solution is made up to a bulk of about 200 cc., 50 cc. of sodium thio-sulphate is added and the solution is heated to boiling and boiled for five minutes; this precipitates the copper as sulphide which is filtered off, dried and ignited ~~as~~ to constant weight.

Zinc.--Add to the filtrate from the copper a large excess of ammonium sodium hydrogen phosphate, neutralize very carefully with ammonia drop by drop, adding a drop or two additional, then about 1cc. of acetic acid and warm gently until the flocculent precipitate of zinc ammonium phosphate has settled completely as a dense crystalline powder, which, after washing with hot water, is dried, precipitate separated from the filter paper, filter paper burned to ash, the ash and dried precipitate ignited gently at first, then for a few minutes at a bright red heat. and weighed as zinc pyro-phosphate.

For the determination of phosphorus in phosphor bronze, the following method by C. B. Dudley of the Pennsylvania R.R. was employed. ( Am. Eng. and R. R. Jour. Vol. 68, p. 128 ).

To 1 gm. of borings, add 25 cc. aqua regia. Cover beaker and allow to dissolve. Heat near boiling point for an half-hour. Add 25 cc. of distilled water and then 20 cc. of con. c. p. ammonia, (sp. g. 0.90). Add 50 cc. of ammonium sulphide solution. Most of the copper and lead is precipitated as sulphide while tin and $H_3PO_4$ are in solution which is clear yellow. Digest at boiling point for twenty minutes. Allow to settle, filter through a 9 cm. filter into an Erlenmeyer flask of 300 cc. capacity. Filter and wash as follows:-Pour clear liquid on filter and allow most of it to run through. Then pour remaining liquid along with precipitate on filter, and allow all to go through that will. Put filter with precipitate on it back into beaker and add 50 cc. of the ammonium sulphide wash water. Warm and stir occasionally for ten minutes to get as complete solution and diffusion of dissolved material as possible, then pour everything onto another filter and allow all that will to go through.

Wash on filter with 50 cc. more of ammonium sulphide solution. This gives about 200 cc. of filtrate. Add 10 cc. of magnesia mixture and shake. Put flask in ice water for two hours with occasional shaking. Filter through a 7 cm..filter and wash with ammonia till $AgNO_3$ gives little test. Add 10 cc. dilute HCl to flask and dissolve precipitate. Then with liquid in flask dissolve precipitate on filter, running into beaker. Wash flask and water with same dilute HCl to make volume of filtrate about 30 cc. Add 5 cc. magnesia mixture and 10 cc. c. p. ammonia; agitate put in ice water and allow to stand for two hours. Filter onto a 5 cm. filter, wash with same ammonia water until washings react slightly with $AgNO_3$ . Smoke off filter, ignite until white and weigh.

The following solutions were used in the above determination:-

Aqua Regia--Equal parts $HNO_3$ and HCl by volume.

Ammonium sulphide wash water--3 parts distilled water, 1 part of ammonium sulphide.

Magnesia Mixture-- 66 gms. crystallized c. p. $MgCl_2$ and 168 gms. c. p. ammonium chloride in 780 cc. distilled water; add 420 cc. c. p. ammonium hydroxide ( sp. g. 0.96 ). Stand two days and filter.

Ammonia wash water--800 cc. water; 200 cc. c. p. ammonia (sp. g. 0.90); 25 gms. ammonium nitrate. Filter.

27.93% $Mg_2P_2O_7$ equals phosphorus.

2. Iron.

The methods used in the analysis were those given in Blairs'

"Chemical Analysis of Iron".

3. Brass.

The brass bearing metal was analyzed by a combination of the ordinary gravimetric method and the electrolytic method,the following method being employed:-

A sample weighing 0.5 g. was taken. This is dissolved in a small quantity of dilute nitric acid, and the solution evaporated to dryness on the awater-bath. The residue is moistened with dilute nitric acid, dissolved in a small quantity of hot water, and any stannic oxide appearing in the solution removed by filtration. The tin was determined by the ordinary method i.e by igniting and weighing as stannic oxide. The filtrate from the oxide of tin is evaporated on the water-bath in the presence of a slight excess of sulphuric acid until the odor of nitric acid can no longer be detected. The residue is moistened with a few drops of dilute sulphuric acid, treated with hot water, and any lead sulphate filtered off, dried, ignited, and weighed.

About 5 cc. of concentrated nitric acid are now added to the filtrate from the lead sulphate, which is diluted to about 150 cc., and the copper precipitated electrolytically, a rotating platinum spiral being used as the anode and a copper dish as the cathode. In consequence of the rotating anode a high current density was employed,from 3-4 amperes. When the separation of the copper is complete, the solution containing the zinc is poured off, and is again evaporated on the water-bath to remove nitric acid. The residue is dissolved in a small quantity of water and a slight excess of ammonia added, when any iron present will be precipitated as ferric hydroxide and can be re-

moved by filtration. Ammonium oxalate is now added to the solution containing the zinc, and this element is precipitated as metal. The same electrodeupon which the copper has been precipitated can be used for receiving the zinc. By this the necessity of preparing a special copper plated electrode is avoided.

METHODS FOR THE ANALYSIS OF THE OILS.

1. Specific Gravity.

The specific gravities of the oils were determined by means of a pycnometer at the temperature that the experiments were to be conducted.

2. Free Mineral Acid.

The charge consisting of 10 cc. was boiled with water until all the free mineral acid was taken up. This wash water was then titrated with tenth normal potassium hydroxide, using phenolphthalein as indicator. The mineral acid value represents the milligrams of KOH required to neutralize the free mineral acid in 1.0 gram of oil.

3.Determination of Organic Oil.

The following method by A. F. Young and B. F. Baker (Chem. News Aug. 1'02),was employed. A flask of 250 cc. capacity has a graduated glass tube, capable of holding 50 cc.,ground accurately into its neck. Schuman's specific gravity bottle for cement is used. Into bottle with tube removed measure 20 cc. of lubricant. Add 100 cc. of a solution of caustic potash, made by dissolving about 100 grams of the alkali in one liter of 50% alcohol.Fit a reflux condenser vertically to the neck of the flask and heat for an half hour on the water bath. When saponification is com-

plete, remove the condenser and fit in the graduated tube. Add cold distilled water through this tube, 50 cc. at a time, shaking the flask until the potash soap has been completely dissolved. Sufficient water must be added to bring the mineral oil well up into the graduated tube. Allow complete separation to occur and read off the volume of mineral oil. When the proportion of organic acid was small, as found by using 20 cc. of the oil, the experiment was repeated using instead 50 cc. of the lubricant thus diminishing error.

4. Determination of the Iodine Absorption Value.

For the full details of this method see Bulletin No. 46, U. S. Department of Agriculture, pages 50 and 51. (Revised Edition). An outline of the method is as follows:- About 1 gram of the oil is placed in a glass stoppered flask holding about 300 cc. together with 10 cc. of chloroform and complete solution allowed to take place. Then 30 cc. of the iodine solution were added and the flask allowed to stand in a dark place with occasional shaking for at least three hours. After absorption, 100 cc. of distilled water and 20 cc. of the potassium iodide solution were added to the contents of the flask. The excess of the iodine is taken up with the sodium thiosulphate solution, which is run in gradually, with constant shaking, until the yellow color of the solution has almost disappeared. A few drops of starch paste are added, and the titration continued until the blue color has entirely disappeared. Toward the end of the reaction the flask should be stoppered and violently shaken, so that any iodine remaining in solution may be taken up by the potassium iodide solution in the water.

Characteristics of a good bearing metal.

1. It must be of the best composition possible and also be uniform throughout.

2. It must be sufficiently plastic to conform to the shape of the journal and yet have strength enough to bear the load.

3. It must not overheat because, (a) its liability of fusion and (b) danger of decomposition of oil.

4. It must have a sufficient percentage of lead for the desirable plasticity and rate of wear. The increased percentage of lead is, however, limited by the increased friction.

A good lubricant should have

1. Sufficient body to keep the surfaces apart under maximum pressure.

2. Greatest possible fluidity consistent with the foregoing condition.

3. Lowest possible coefficient of friction.

4. Greatest capacity for storing and carrying off heat.

5. A high temperature of decomposition.

6. Power to resist oxidation in the air.

7. The least amount of corrosive action as possible on metals.

Summary of conclusions and results.

The loss in weight with the iron samples is less in all cases than with any of the others.

The loss in weight of the non-pareil antifriction metal is a little greater in general than with the quality antifriction babbitt. Theae are compared because of the high percentages of lead in each. The first sample contains 95% lead while the second contains 82%. Hence the loss in weight is somewhat greater in general as the percentage of lead increases.

It is also likely, since the greater amount of tin is contained in the second metal, that as the tin increases in such alloys, its effect is to lessen the action of the oil upon it.

The largest loss is with the phosphor bronze and next to that the brass. We see from our analyses that the phosphor bronze contains the larger percentage of copper. Its percentage of tin may likely tend to lessen the action of the oil. But as the brass contains nearly the same amount of copper as the phosphor bronze and since its action is less than that of the phosphor bronze we might ascribe this action to the presence of the zinc.

It is seen that in general the loss in weight of the metals is a little greater in those tubes which were exposed to the air. A practical deduction from the above conclusion would be that bearing surfaces as far as possible should be enclosed so as not to be too much exposed to the action of the air.

It is also seen that the action is a little greater as the mineral acid value rises. This does not seem to apply in general to the presence of the organic acids. It would then seem that when the temperature does not rise too high for the decomposition of the organic oils, thereby liberating the free fatty acid which would attack the metal, the greatest corrosive action would be exerted by the free mineral acid present.

The color of the oil darkens in each case, both when open to the air and closed, but in general the darker color is in the open tubes. This may be due to the greater action on the metals in the open tubes. In fact there were slight precipitates in some of the open tubes.

The surfaces of the metals were not corroded to any appreciable extent.

# BEARING METALS.

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32 : 381.
32 : 625.

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Closed Tubes

| me of tal | Name of Oil | Wt. of Metal Grms Before Exposure | Wt. of Metal Grms After Exposure | Loss % | Color Of Oil Before Exposure | Color Of Oil After Exposure |
|---|---|---|---|---|---|---|
| sphor onze | Min. Cyl. + Mach. | 3.5372 | 3.5359 | .036 | Dark Green | Dark Brown |
| " | Dynamo + Engine | 5.2734 | 5.2701 | .062 | O.N. Tone | Black |
| " | Engine No. 1 | 7.0484 | 7.0455 | .041 | O.R. N. Tone (Bloom) | " |
| " | Dark Cylinder | 6.1914 | 6.1881 | .053 | Dark Brown Green | " |

The significance of the notation used with reference to the colors of the oils is;

O, orange

R, red

G, green

O. R, orange red

N, normal

Bl, bloom

etc.

T = tone.

| | | | | | | |
|---|---|---|---|---|---|---|
| " | Tallow | 2.9870 | 2.9849 | .070 | Green | Black |
| " | Dyn. r H.S. Engine | 2.5208 | 2.5201 | .027 | Y.N. Tone V. Sl. Bl. | O. Shade 1 |
| " | Keystone Dyn. r Eng. | 4.5441 | 4.5433 | .017 | O.Y. N Tone Some. Bl. | R. O. Shade 2 |
| rass | Min. Cyl. + Machine | 7.5976 | 7.5948 | .036 | Dark Green | Black |
| " | Dynamo + Engine | 6.8435 | 6.8395 | .058 | O.N. Tone Sl. Bl. | " |
| " | Engine No. 1 | 6.4460 | —— | —— | O.R.N. Tone Bloom | " |
| " | Dark Cylinder | 9.1263 | 9.1221 | .046 | D'k Brown Green | " |
| " | Light Oil | 7.7192 | 7.7171 | .027 | R.N. Tone Much Bloom | Black (Bloom) |

Closed Tubes

| Name of Metal | Name of Oil | Wt. of Metal Grms | | Loss % | Color Of Oils | |
|---|---|---|---|---|---|---|
| | | Before Exposure | After Exposure | | Before Exposure | After Exposure |
| Brass | Engine No. 2 | 6.2290 | 6.2264 | .041 | O Shade 1 | Black |
| " | Str. Min. Eng. Oil | 6.6127 | 6.6093 | .051 | O Y N Tone V. Sl. Bloom | Dark Brown |
| " | Cyl. Oil With Tallow | 7.1799 | 7.1789 | .013 | Heavy D. Green | Black |
| " | Dyn & High Speed Eng | 10.1991 | 10.1957 | .038 | Y. N. Tone V. Sl. Bl. | D. Reddish Brown |
| " | Keystone Dyn. & Eng. | 8.2240 | 8.2231 | .011 | Y. O. N Tone Some Bl. | Black |
| Iron Par nti-Fric. | Min. Cyl. & Mach. Oil | 3.7188 | 3.7175 | .034 | Dark Green | " |
| " | Dynamo & Engine | 2.7832 | 2.7822 | .035 | O. N. Tone | " |
| " | Engine No. 1 | 3.6799 | 3.6782 | .046 | O. R. N. Tone Bloom | Red Shade 2 |
| " | Dark Cylinder | 3.3899 | 3.3884 | .044 | D. Greenish Brown | Black |
| " | Light | 3.1040 | 3.1028 | .038 | R. N. Tone Much Bl. | Olive Green & Bl. |
| " | Engine No. 2 | 2.5218 | 2.5213 | .019 | O Shade 1 Sl. Bl. | Dark Red Little Bl. |
| " | Str. Min. Engine | 2.7127 | 2.71265 | .0018 | O Y. N Tone V. Sl. Bl. | O. R. Shade 2 |
| " | Cyl. Oil With Tallow | 2.6387 | 2.6367 | .075 | Heavy D Green | Black |
| " | Dyn. & High Speed Eng | 3.6706 | 3.6694 | .032 | Y. N. Tone V. Sl. Bl. | Red Shade 2 |
| " | Keystone Dyn. & Eng | 6.2527 | 6.2514 | .020 | Y. O. N Tone Bl. | Dark Brown |
| Cast Iron (Grey) | Min. Cyl. & Mach. Oil | 5.7930 | 5.7926 | .007 | Dark Green | Black |
| " | Dynamo & Engine | 6.1859 | 6.1852 | .011 | O. N. Tone | " |
| " | Engine No. 1 | 6.2930 | 6.2907 | .086 | O. R. N Tone | Red Shade 2 |
| " | Dark Cylinder | 6.03885 | 6.03105 | .013 | D. Brown Green | Black |
| " | Light | 6.3739 | — | | Red N. Tone Much Bl. | D. Bluish Green |
| " | Engine No. 2 | 6.9356 | 6.9435 | Gain | O. Shade 1 Sl. Bl. | Black |
| " | Str. Min Engine | 6.3851 | 6.3848 | .004 | O. Y. N. Tone V. Sl. Bl. | R. O. Shade 2 |
| " | Cyl. Oil & Tallow | 6.5978 | 6.5973 | .007 | Heavy D. Green | Black |
| " | Dyn. & H. S. Engine | 5.1134 | 5.1129 | .0097 | Y. N. Tone V. Sl. Bl. | O Shade 1 |
| " | Keystone Dyn. & Eng. | 4.3220 | 4.3218 | .0046 | Y. O. N Tone Bl. | Red Shade 2 |

| Name of Oil | Specific Gravity | Free Fatty Acid | Mineral Acid Value | Iodine Value (% I absorbed) |
|---|---|---|---|---|
| Min. Cyl. Mach. Oil | .854 | 1.5 | .743 | 17.64 |
| Dyn. & Eng. Oil | .874 | 6.0 | 1.010 | 22.35 |
| Engine No. 1 | .874 | 2.5 | 1.335 | 21.92 |
| Dark Cyl. Oil | .873 | 4.0 | 1.090 | 20.50 |
| Light Oil | .820 | 7.5 | .963 | 22.17 |
| Engine No. 2 | .865 | 3.6 | .194 | 13.18 |
| Str. Min. Eng. Oil | .864 | 2.0 | .160 | 20.22 |
| Cyl. Oil With Tallow | .866 | 11.5 | .210 | 26.31 |
| Dyn. & High Speed Eng. | .830 | 5.0 | .711 | 21.78 |
| Keystone Dyn. Eng. | .840 | 2.0 | .249 | 20.43 |

| Name of Metal | Lead | Tin | Antimiiy | Copper | Iron | Silica | Zinc | Phos. |
|---|---|---|---|---|---|---|---|---|
| Non-Pareil Anti Frictin | 95 | 1 | 3.5 | | | | | |
| Quality Anti Fric. Babbitt | 82 | 10 | 5 | 2 | | | | |
| Brass | Trace | 1.996 | | 82.18 | .672 | | 15.02 | |
| Phosphor Bronze | | 9.8 | | 89.10 | | | | .62 |
| Iron | | | | | 94.2 | 2.51 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cylinder Light Oil | 6.9624 | 6.9604 | 029 | Green R. N. Tone | Very Dark Green | | |
| | | 8.9725 | 8.9681 | 041 | | | | |

## Open Tubes.

| Name of Metal | Name of Oil | Wt. of Metal-Grms | | Loss % | Color Of Oil | |
|---|---|---|---|---|---|---|
| | | Before Exposure | After Exposure | | Before Exposure | After Exposure |
| Phosphor Bronze | Min. Cyl. + Mach. | 5.3043 | 5.3021 | .041 | Dark Green | Black |
| " | Dynamo Engine. | 6.2583 | 6.2543 | .064 | O. N. Tone | " |
| " | Engine No. 1 | 4.3694 | 4.3675 | .043 | O.R. N. Tone (Bloom) | " |
| " | Dark Cylinder | 2.3886 | 2.3874 | .050 | Dark Brown Green | " |
| " | Light Oil. | 5.5221 | 5.5224 | ? | R. N. Tone (Bloom). | Black (Bloom) |
| " | Engine No. 2 | 8.5668 | 8.5618 | .058 | O. Shade 1 (Slgt. Bloom). | Black |
| " | Str. Min. Oil. | 5.1610 | 5.1578 | .062 | O.Y.N. Tone (Very Slght. Bloom). | Reddish Brown |
| " | Cyl. Oil & Tallow | 4.8814 | 4.8806 | .016 | Heavy Drk. Green. | Black |
| " | Dyn. + H.S. Engine | 8.1852 | 8.1820 | .039 | Y.N. Tone (Very Slght. Bloom) | Red Shade 2 |
| " | Keystone. Dyn. Eng. | 6.1453 | 6.1441 | .019 | Y.O.N. Tone (Bloom). | Black |
| Q.A. Babbitt | Min. Cyl. + Mach. | 2.8294 | 2.8284 | .035 | Dark Green | " |
| " | Dynamo & Engine | 4.0811 | 4.0746 | .037 | N. Tone Orange | " |
| " | Engine No. 1 | 3.0604 | 3.0588 | .052 | O.R. N. Tone | " |
| " | Dark Cylinder | 2.5759 | 2.5749 | .039 | Drk. Brown Green | " |
| " | Light Oil. | 3.1157 | 3.1146 | .035 | R.N. Tone (Heavy Bloom) | Blue Green Shade 3 (Bloom) |
| " | Engine No. 2 | 2.7158 | 2.7150 | .029 | O. Shade 1 (Slight Bloom) | Very Dark Red Brown |
| " | Str. Min. Oil | 2.8559 | 2.8556 | .001 | O.Y.N. Tone (Very Slight Bloom) | Orange Shade 1 |
| " | Cyl. Oil + Tallow | 4.0767 | 4.0733 | .083 | Heavy Dark Green | Black |
| " | Dyn. + H.S. Engine | 3.7867 | 3.7855 | .032 | Y.N. Tone (Very Slight Bloom) | Red Orange Shade 1 |
| " | Keystone Dyn. Eng. | 4.0132 | 4.0121 | .027 | O.Y.N. Tone (Slight Bloom) | Red Shade 2 |
| Brass | Min. Cyl. + Mach. | 7.9373 | 7.9341 | .041 | Dark Green | Black |
| " | Dynamo Engine. | 7.0217 | 7.0173 | .063 | O.N. Tone (slight Bloom) | " |
| " | Engine No. 1 | 6.5779 | 6.5736 | .065 | O.R.N. Tone (Bloom) | " |
| " | Dark Cylinder | 8.9725 | 8.9681 | .049 | Drk. Brown Green | " |
| " | Light Oil. | 6.9624 | 6.9604 | .029 | R.N. Tone | Very Dark Green |

| Name of Metal | Name of Oil | Wt of Metal-Grms. | | Loss % | Color of Oil | |
|---|---|---|---|---|---|---|
| | | Before Exposure | After Exposure | | Before Exposure | After Exposure |
| Brass | Engine No. 2 | 7.4883 | 7.4853 | .040 | Orange Shade 1 | Black |
| " | Str. Min. Eng. Oil. | 7.9080 | 7.8939 | .051 | O.Y.N.Tone (Very Slight Bloom) | Dark Brown. |
| " | Cyl. Oil With Tallow | 6.9774 | Tube Lost | — | Heavy Dark Green | Black |
| " | Dyn.+High Speed Eng. | 6.1769 | Tube Broken | — | Y.N.Tone (Very Slight Blm) | Dark Brown |
| " | Keystone Dyn.+Eng. | 5.9412 | 5.9403 | .015 | Y.O.N.Tone (Bloom) | Black |
| N.P. Anti-Friction | Min. Cyl. + Machine | 2.2344 | 2.2336 | .036 | Dark Green | " |
| " | Dynamo + Engine | 4.7992 | Tube Broken | — | O.N.Tone | " |
| " | Engine No. 1 | 4.3694 | 4.3671 | .053 | O.R.N.Tone (Bloom) | " |
| " | Dark Cylinder | 2.3886 | 2.3877 | .037 | Dark Greenish Brown. | " |
| " | Light Oil | 2.5899 | 2.5589 | .039 | R.N.Tone (Much Bloom) | B.G. Shade 3 (Bloom) |
| " | Engine No. 2 | 3.6589 | 3.6582 | .019 | O. Shade 1 (Slight Bloom) | Dark Red (Slight Bloom) |
| " | Str. Min. Engine | 4.0711 | 4.0709 | .004 | O.Y.N.Tone (Very Slight Blm) | Red Shade 2. |
| " | Cyl. Oil With Tallow | 1.4773 | 1.4772 | .068 | Heavy Dark Green | Black |
| " | Dyn.+High Speed Eng. | 3.6034 | 3.6021 | .037 | Y.N.Tone (Very Slight Blm) | Red Orange Shade 2. |
| " | Keystone Dyn.+Eng. | 4.4923 | 4.4911 | .027 | Y.O.N.Tone (Bloom) | Dark Red |
| Cast Iron (Grey) | Min. Cyl. + Machine | 5.1511 | 5.1505 | .011 | Dark Green. | Black |
| " | Dynamo Engine | 5.4241 | 5.4234 | .013 | O.N.Tone | " |
| " | Engine No. 1 | 7.0870 | 7.0841 | .041 | O.R. N.Tone | " |
| " | Dark Cylinder | 3.7561 | 3.7555 | .016 | Dark Brownish Green | " |
| " | Light Oil | 6.6555 | 6.6548 | .010 | Red N.Tone (Much Bloom) | Dark Greenish Brown. |
| " | Engine No. 2. | 5.4510 | 5.4510 | — | O. Shade 1 (Slight Blm) | Very Dark Brown. |
| " | Str. Min. Engine | 6.2815 | 6.2812 | .005 | O.Y.N.Tone (Very Slight Blm) | Orange Shade 1 |
| " | Cyl. Oil With Tallow | 6.6011 | 6.6005 | .007 | Heavy Dark Green | Black |
| " | Dyn.+High Speed Eng. | 6.5400 | 6.5390 | .015 | Y.N.Tone (Very Slight Blm) | Red Orange Shade 1 |
| " | Keystone Dyn.+Eng. | 5.1717 | 5.1714 | .005 | Y.O.N.Tone (Bloom) | Very Dk Reddish Brown. |